RESEARCH DEPARTMENT

SYMPOSIUM ON ELECTROMAGNETIC THEORY AND ANTENNAS
COPENHAGEN, 25th - 30th JUNE 1962

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1. INTRODUCTION

The Symposium was sponsored jointly by the International Scientific Radio Union (U.R.S.I.), the Danish National Committee of U.R.S.I., the Technical University of Denmark, and the Danish Academy of Technical Sciences. It was held at the Technical University of Denmark from June 25th to 30th inclusive, and was attended by about 320 delegates.

A total of 140 papers was presented, covering the following topics:

1. Scattering and Diffraction
2. Antenna Studies
3. Anisotropic Media
4. Surface Waves
5. Ferrites in Waveguides
6. Waveguides and Mode Propagation
7. Media with Random Propagation Characteristics
8. Partial Coherence
9. Stratified Media
10. Miscellaneous topics

Of the 180 authors, just over 50% came from the U.S. and 5% from the Eastern bloc of countries. The large number of papers presented meant that for about one half of the time it was necessary to have three sessions going on simultaneously. It is interesting to reflect that the material presented at this one Conference probably exceeded, at least in the volume, the whole of that published on the subject of aerials up to the outbreak of the Second World War. The enormous current interest in the study of electromagnetic theory and of aerials stems from four main causes:

(i) the use of the higher frequency bands and of new techniques, which demand a greater degree of sophisitication in the aerials;

(ii) the increasing interest of physicists and mathematicians in the subject, following their association with the work at the outbreak of the Second World War;

(iii) the availability of computers to solve numerical problems too laborious to be worth attempting by manual methods;

(iv) the problems arising in space research.

Despite the effort devoted to aerial theory during the past twenty years, it still involves a great deal of approximation. Theoretical papers often introduce idealizations which may make them seem rather remote from practice; nevertheless, these are useful if they help to elucidate general principles. Only brief summaries of the papers presented at the Symposium are at present available to the delegates; the complete papers will follow later. In this report it is therefore proposed to indicate only the broad trends of current research, with more detailed reference to those papers directly related to broadcasting problems. A volume of the summaries is available to any one interested.

2. CURRENT RESEARCH PROJECTS

2.1. Scattering and Diffraction

This session opened with an interesting general review by Keller of the purpose and methods of scattering and diffraction theory. The work in this field over the past twenty years has led to the conclusion that propagation can well be described by a combination of geometrical optics, together with processes which give rise to additional rays; the important point is that the sources of the latter are essentially local to the discontinuity or irregularity which gives rise to them. This means that it is permissible to synthesize complex arrangements from simple ones, and it is consequently worth while solving the simple cases as well as possible, in order to understand the principles involved. Keller gave as examples of the main types of problem related to his subject the propagation of waves, reflexion and refraction, diffraction by an edge, vertex or curved surface, focusing at a caustic, the formation of shadow bands, coalescence of a shadow boundary and a caustic, and the propagation of surface waves.

There were a number of associated papers dealing with specific reflexion and diffraction problems, for example a thin oblate spheroid (which in the limit degenerates into a disc), a finite cone, a strip and a non-circular aperture. One paper concerned the diffraction of waves by several smooth cylinders in tandem (equivalent to propagation over several mountains). The theoretical method was complex, and we felt that the results obtained could have been obtained with reasonable accuracy by applying what Keller described as the "principle of local fields", involving in this case the judicious use of Fresnel integrals.

Associated with this group of papers were two dealing with "models" of the atmosphere of the moon and of Venus, with the object of explaining observations of the measured radiation from these planets.

2.2. Antenna Studies

2.2.1. Spiral and Log-Periodic Aerials

Two papers were presented by workers who have been associated with these types of aerials since their conception. Rumsey made a further contribution to the theory of the spiral, solving Maxwell's equations for the generalized case of a plane

spiral aerial consisting of an infinite number of equally-spaced conductors. Thus in his model the plane takes the form of an anisotropic sheet which is perfectly conducting only in the direction of the spirals. Two possible excitation modes for the conductors are possible (clockwise and anti-clockwise); the solution to the equations indicate that only one of these modes can be achieved in a practical aerial. In a paper by DuHamel the theoretical basis for the design of log-periodic aerials was discussed; this was put forward not so much as a simplification but as a generalization which was more illuminating than previous treatments.

2.2.2. Radiation Pattern Synthesis

The synthesis of antenna patterns has an important practical application in the broadcasting field; one example is the design of a u.h.f. transmitting aerial of high gain, with the vertical radiation pattern "gap-filled". The user is not concerned with the *phase* of the received field, but only with the amplitude, and this makes the problem difficult to analyse mathematically. Two papers were presented proposing new methods of tackling this problem, but we felt that neither has yet been sufficiently developed to enable them to be applied to practical problems without further development.

One of these papers (by Proctor) introduced three terms; one was proportional to the square of the difference between the required and actual powers, and the other two were proportional to the square of the derivative of the separate amplitude and phase distributions, corresponding to 'smoothness' factors. The relative importance of the three terms was adjusted by multiplying them by weighting factors, and their sum was then minimized by successive approximations. The difficulties we saw with Proctor's method (which is not being pursued due to lack of funds) are first that a solution can only be obtained with the help of a digital computer, and secondly that there are no obvious criteria for choosing the weighting factors.

There were three related papers in this session dealing with radar and radio-astronomy applications.

Two papers were presented on conditions in or near the radiating apertures of aerials, a subject of increasing interest in calculating the far-field performance of aerials (which is inconvenient to measure if the aperture is large) from the near-field characteristics. One paper dealt with a modification to the well-known formula for coupling between two aerials, so as to enable it to be applied to aerials having spacings comparable with their apertures. Basically the problem involves the calculation of mutual impedance; in fact the method presented appeared to be merely a generalization of the well-known Brillouin method for the calculation of the mutual impedance between dipoles.

2.2.3. Radiation over Inhomogeneous Ground

Two closely related papers concerning the launching of waves at low angles from base-fed vertical aerials were presented, one by Wait and one by Andersen. This problem is of interest in medium-frequency broadcasting* because the intensity of the low-angle sky-wave is influenced to a considerable extent by the characteristics of the ground for distances of many wavelengths in the direction of propagation. Wait discussed the amount by which the earth system must be extended in the direction of

*For example, in connexion with the proposed overseas high-power installations.

propagation in order to simulate an infinite perfectly-conducting ground plane, while Andersen considered the two-dimensional problem of a unipole located near discontinuities in the ground. Both authors indirectly acknowledged that their methods were based on Monteath's application of the compensation theorem.

2.2.4. Characteristics of Aerials Submerged in the Earth

The properties of aerials submerged in the earth have become important in the location of certain rock formations, and also for communication with submarines. Two studies (one theoretical and one experimental) of this problem were presented.

2.2.5. Miscellaneous Aerials

The proposal to use an island as a natural low-frequency "slot" in the sea, which may be regarded as a highly-conducting plane, (see I.R.E. PGAP September 1960) - was discussed by Staras. He concluded that the island is too good a conductor for this purpose, and that the radiation is virtually equivalent to that of a Beverage aerial formed by the driving lead.

A contribution from Japan described a broadband "blade" aerial (118 - 144 Mc/s) for mounting on an aeroplane. It consists of a multi-conductor folded unipole having a maximum dimension of one-eighth wavelength; no information on the efficiency of this aerial was available.

King dealt with the problems of deviations from the usually assumed sinusoidal current distribution, and its effect on the coupling between the elements of end-fire and broadside arrays. It involved mutual impedance calculations between parallel elements in terms of the "King-approximation" to the true aerial current distribution; the conclusion was that in general it is difficult to achieve the required uniformity of the currents between the elements with conventional methods of feeding. This work has little application to the curtain arrays used by the B.B.C.

Ghose described an "active electronic antenna" in which arbitrarily-spaced aerials have their outputs phase-locked before adding. This is in effect an aerial which steers its beam on to the wanted source, independent of the direction of the source. This is not a new idea inprinciple - it is used for instance in phase-locked diversity reception on s.h.f. links.

2.2.6. Radiating Elements

This session was directly connected with topics studied in B.B.C. Research Department.

Hallén presented a new solution to an old problem - the current distribution on a cylindrical aerial. He assumed thin-walled tube (to avoid having to deal with the endcaps) and took the current distribution as an infinite series of travelling waves. Hallén claimed to have solved the resulting integral equation exactly, and stated that his earlier approximate solutions were in fact correct series expansions of the exact solution. The value of this solution in solving practical problems must await a more detailed study of the full paper, when available.

Duncan also dealt with the current distribution on a thin-walled tube, and posed the old question of the singularity introduced by an infinitesimal gap. He concluded that in practice the effect is negligible, and is in fact much less than that of the finitely-spaced feed line.

Plonus made a new contribution to the solution of Schelkunoff's biconical aerial; as a first approximation, he started on the difficult problem of 'matching' the mode coefficients at the boundary sphere by equating corresponding modes, and then applying the Schelkunoff relationships between the mode coefficients. This could well be a useful contribution to the subject, but requires further study when the full paper is available.

Robin and Poincelot obtained a solution to the radiation from a sphere, energized across a diametral plane. This problem has been solved exactly previously, but the authors claim that their result is more rapidly convergent. Their derivation of the radiation resistance was claimed to be original.

Spitz described a relatively new class of broad-band aerial, depending on the principle of coupling one transmission line with another. The former sustains a T.E.M. wave; it does not itself radiate, but when coupled to a line with a slightly reduced velocity of propagation, produces transverse currents which radiate in the axial direction. An example of such an arrangement is the 'saucisson' antenna, a helix surrounding a two-wire line; at the mid-band frequency this has a gain comparable with a Yagi of the same length, but has a bandwidth of about an octave. Spitz gave other examples.

One limitation on the noise temperature of radio-astronomy parabolic telescopes is caused by the 'spill-over' of their radiation patterns in the direction of the ground; an associated difficulty is that the effective ground temperature varies as the aerial tracks. Jasik proposed to overcome this difficulty by better shaping of the secondary aperture distribution, using relatively large primary feed apertures (about 5 wavelengths diameter) comprising rings of aerials. In the case he described a three-ring feed aerial corresponded to a spill-over noise temperature of less than 2°K, compared with 40°K for typical existing feeds.

2.3. Anisotropic Media

This session dealt with wave propagation in media having anisotropic properties; a familiar example of such a medium is the ionosphere, whose anisotropic properties are caused by the earth's magnetic field. Attention was mainly confined to the additional effects caused by the motion of the positive ions in a plasma of this type. This motion gives rise to kinetic waves (known as hydromagnetic waves) which are propagated with the velocity of sound. An interesting account of the relationship between hydromagnetic wave propagation and the magneto-ionic theory was given by Hines. Although the ionic movement in the ionosphere is insignificant at radio frequencies, it becomes important at low frequencies in the presence of strong magnetic fields.

Radiation from a source in a plasma region was dealt with in four papers (including one by Clemmow and one by Budden, both of Cambridge University); a practical example is the problem of determining the radiation pattern and impedance of an aerial when immersed in the ionosphere, e.g. when mounted on a rocket.

2.4. Surface Waves

The concept of surface and "leaky" waves is applicable to a variety of electromagnetic phenomena. Leaky waves differ from surface waves in that they are propagated with a phase velocity greater than that of light; radiation therefore takes place at an angle directed away from the surface. An example of a leaky wave aerial is the slotted waveguide. The relation between leaky-wave aerials and the more familiar types of end-fire aerials such as Yagis and dielectric rods was also discussed. A Yagi or log-periodic aerial, for instance, can be regarded as an approximation to a periodically-modulated launching device which supports a leaky-wave mode; this correspondence between an aerial and the propagation mechanism is helpful in understanding the former.

Billström described a method for independently controlling the amplitude and phase of the radiated field launched by a surface wave, by modulation of the surface reactance.

2.5. Ferrites in Waveguides

It was not possible to attend this session. It is, however, worth while mentioning that ferrites are widely used nowadays in conjunction with waveguides; they can separate a plane wave in general into two elliptically-polarized waves, which propagate with different velocities. As a result, interesting and useful forms of wave propagation occur in ferrite-loaded guides.

2.6. Waveguides and Mode Propagation

Waveguides with anisotropic impedance walls are mathematical models for practical structures such as the helical-waveguide and the lined waveguide. Papers on elliptical and optical waveguides were also included.

An interesting account was given by Meinke of his application of conformal transformations to electromagnetic field problems, which has application to the design of high-power waveguides and wideband aerials. His method is an extension of the well-known technique for transforming the field distribution between conductors of arbitrary shape into a rectangular field. Meinke modifies the permeability of the field space in the rectangular co-ordinate plane, in accordance with the ratio of the areas of the corresponding curvilinear rectangles in the two planes; the field space in the rectangular plane is therefore assumed to have a non-uniform permeability. The wave equations for propagation normal to the plane are then solved, taking into account the non-uniform permeability; in this way, for example, the velocities of propagation of the various modes supported by a waveguide of irregular shape may be calculated. Calculations of this nature have been shown experimentally to be extremely accurate. Meinke is now using a variation of this method to determine the input impedance of, and radiation from, a unipole connected to a coaxial transmission line. This is a somewhat different problem because a three-dimensional field transformation is involved; this is achieved by modifying the dielectric constant in addition to the permeability. This work is not yet complete; it will be interesting to see how the results obtained by this novel approach to the much-discussed dipole problem compare with those obtained by other methods.

2.7. Random Media

Silver gave a helpful review of what he called the "methodologies" used in the analysis of propagation, comparing the different approaches used in the X-ray, optical, microwave, u.h.f. and medium-frequency bands. In X-rays, for example, the interest is in the medium; in the other fields the communication problem is uppermost, although in these too the techniques and language differ.

In scattering theory two types of "model" have been used. In one there are discrete scattering sources, whereas in the other the medium is regarded as continuous but subject to temporal variations. These two ways of looking at the problem were later elaborated on by Bremmer and Twersky respectively.

2.8. Partial Coherence

In optics no detector can record the rapidly-varying intensity; only the time average can be measured. Optics is therefore likely to benefit from the greater use of the statistical theory previously used in the radio field to handle such topics as thermal noise; it may be regarded as a language rather than a science.

2.9. Stratified Media

Stratified media fall into the general class of anisotropic media, and the division in the Symposium was presumably based on convenience.

The theory of stratified media has practical applications to ionospheric and tropospheric propagation (e.g. ducting).

2.10. Miscellaneous Topics

2.10.1. Radiation Pressure

An interesting paper on the angular momentum of electromagnetic radiation was presented by di Francia. It is well known that electromagnetic radiation exerts a mechanical pressure on a perfectly-absorbing surface, and it can be shown that a circularly-polarized wave can exert a torque on a plate placed normal to the direction of propagation. A circularly-polarized wave may therefore be considered as possessing angular momentum. Since every force has an equal and opposite reaction, this concept opens up the possibility of controlling the attitude of space vehicles by radiating circularly-polarized transmissions. Although the forces involved with conventional powers and frequencies are small they were shown to be sufficient to obtain the desired degree of control.

2.10.2. C.C.I.R. Question on the Directivity of H.F. Arrays at Great Distances

A special meeting took place to discuss a question from the C.C.I.R. Study Group dealing with the desirability of using directional arrays having low sidelobes for h.f. services.

The discussion was limited almost entirely to a consideration of 'wideband' arrays (and in particular the rhombic), as being typical of those used for most point-to-point services, as well as many broadcasting services. A draft reply, previously prepared by Col. J. Lochard, Chairman of Study Group I, was considered.

This included a comment to the effect that log-periodic arrays might offer a satisfactory solution to the problem. It was, however, pointed out that no high-gain log-periodic array has yet been designed, and if it were the cost would be high and the sidelobes probably far from negligible. An additional comment to the effect that the height of the rhombic could be chosen to minimize sidelobes was thought, at least as explained to the meeting, to be invalid. After discussion, therefore, it was agreed to delete these two comments from the reply.

The resulting document was therefore restricted to emphasizing the desirability of using directional arrays having low sidelobes in order to minimize interference, but stated that no immediate recommendation could be made as to the best way of achieving this end; the design of arrays having a performance substantially better than that of the conventional rhombic remains a subject for further study. It was realized that this comment was rather weak; nevertheless it was thought to have some 'political' use in bringing these considerations to the attention of the transmitting authorities.

2.10.3. Log-Periodic Aerials

Sweden has a log-periodic aerial working over the band 2 - 20 Mc/s, but it has only a small gain (about 6 dB over a dipole of optimum height).

The proponents of these aerials were agreed that to compete in gain with an array such as an H4/4/1 would be very expensive and mechanically complicated, especially for high power. A catalogue of all the types manufactured by the Collins Co. was promised by Mr. DuHamel.

2.10.4. Ring Aerials

Professor Sinclair told us that the F.C.C. is showing renewed interest in ring aerials in association with high-power transmitters for medium-frequency broadcasting, to cover those areas at present without a sound service of any kind. The main object would be to increase the groundwave field strength for a given transmitter power.

2.10.5. Aerial Work at Birmingham University

There appears to be a fair amount of work on aerials going on at Birmingham University under Professor Tucker. We were invited to establish contact at a convenient time.

2.10.6. Vertical Radiation Pattern Computer

We received full details of a Dutch computer comparable with Research Department ARPAC, but dealing with vertical rather than horizontal radiation patterns. The information will be studied.

2.10.7. Swedish Tower Design

We saw, from a distance, a Swedish tower 100 m high supporting a television transmitting aerial in addition to acting as a m.f. radiator. Later we learned that this was only about 2 m wide at the base, and that the Swedish designers can provide

relatively slim towers, providing sufficient concrete is used in the foundations. A base of 6 m was suggested by Mr. Strandén as a possibility for a tower 150 m high. The address of a specialist in the construction of such towers is:

Mr. Einar Valberg,
Drottninggatan 50 - 52
Stockholm

This information will be passed to Planning & Installation Department.

3. CONCLUSIONS

Of the large number of papers presented at the Symposium, probably half were of direct or indirect interest to the B.B.C. Those concerning aerials and propagation were naturally of the greatest interest; some of these dealt with problems currently under review in Research Department. The Symposium also provided a valuable opportunity of meeting a large number of the workers who are engaged on research on aerials throughout the world; many fruitful discussions were held and helpful contacts made.

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